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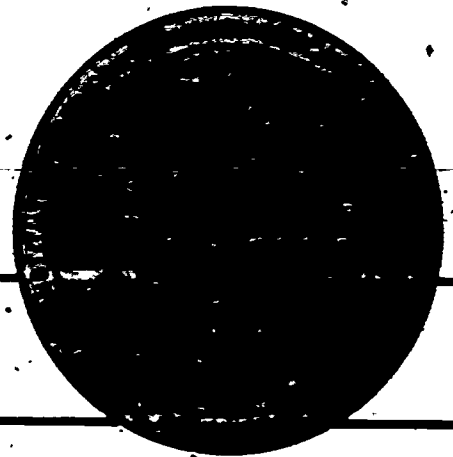
## ABSTRACT

This report gives an overview of a study conducted by the Space Applications Board (SAB) on the practical applications of space systems. In this study, the SAB considered how the nation's space capability might be used to solve problems such as the shortage of food and energy; the improvement of the physical environment; inventorying and monitoring of the earth's land, water, and mineral resources; and limitation of the effects of natural disasters. To accomplish this, fourteen panels were formed to study various aspects of space applications. The work of nine of these panels is discussed: weather and climate; land use planning; agriculture, forest, and range; inland water resources; extractable resources; environmental quality; marine and maritime uses; uses of communications; and materials processing in space. Also discussed is the organizing capability needed for the transition stage in the evolution of space systems. (MH)

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ED127145

# Practical Applications of Space Systems



Space Applications Board

Assembly of Engineering

031 003

## 1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

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## PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering\* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the summer study should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado. Subsequently, the SAB reviewed the work of this group, evaluated

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\*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

its findings, and prepared this report, which presents the SAB's own conclusions and recommendations.

Most of these recommendations relate to future applications of space information and service systems that, in the SAB's judgment, show promise of meeting needs expressed by potential users in the private or the public sector. Several recommendations relate to research or development programs needed to provide the technological capability to meet the needs of potential users. Others deal with organizational or institutional changes (affecting both the public and the private sectors) needed if the socioeconomic benefits offered by the technical capabilities are to be realized.

In the course of the last decade, research and development programs related to practical uses of space systems have been formulated primarily by aerospace technologists, guided largely by their own perceptions of what would constitute useful information and services. There have been few organized efforts to permit users to express their needs and thus have a voice in the planning of new space systems -- systems that future users will, in some cases, have to pay for. It is the SAB's hope that this study will constitute an important step toward greater user involvement.

For the study, user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number of scientists and technologists also participated, functioning essentially as expert consultants. The conclusions of the study are founded on the resulting statements of needs, as expressed by the user community, in light of considerations of practicability provided by space technologists.

While the SAB hopes that the recommendations will be useful, not only to the aerospace and user communities, but also to the legislative and executive branches of the federal government, the study was not designed to make detailed assessments of all of the factors which must be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed, requirements for institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.



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## INTRODUCTION

It was only eighteen years ago that the first artificial earth satellite was placed in orbit. Since then, the United States has carried out a diversified and innovative space program, encompassing many fields of science and technology. The program has been interdisciplinary, employing successfully a synergistic combination of human knowledge, a new capability for managing very complex undertakings, and industrial know-how. It has brought this Nation to a position of leadership in space.

The most visible part of the space program was Project Apollo, which accomplished the goal President Kennedy had set to land men on the moon and return them safely to earth. While Apollo provided an important focus for the Nation's nascent space program, its high public visibility has tended to overshadow other accomplishments. As a result, there is little public understanding of the important activities that constitute the current space program, funded at half the peak level of the Apollo years. During those years the unmanned space science program made vital discoveries about the earth's environment and much was learned about the formation of the solar system. Planetary exploration opened new vistas in science. Technology developed in the space program was applied in activities on earth, in a process sometimes called "spinoff." In addition to science and exploration, use of space systems directly to assist man was a very early part of the program. The first meteorological satellite, TIROS 1, was launched in 1960 and the first active communications satellite, TELSTAR, in 1962. We now take these uses of space systems almost for granted, and fail to realize that the potential for such practical applications has barely been tapped. The Nation has made a vast investment in space and has created a valuable resource of trained and competent engineers, scientists, managers, and skilled workmen in industry, government, and the universities. However, few managers and decision-makers in industry and government who could make use of the information or services which earth satellites can provide have had opportunity to understand the potential or test the applicability of space technology to the solution of their problems.

In 1972 the Space Applications Board (SAB) was formed to consider how the Nation's space capability might be put to work on a much broader basis to help solve some of mankind's truly great and pressing problems such as the shortage of food and energy; the improvement of the physical environment, inventorying and monitoring of the earth's land, water and mineral resources; limitation of the hazards caused by natural disasters such as floods, drought and earthquakes. To accomplish this, members of the SAB were selected primarily from outside the

aerospace community in the "user" world of communications, education, environment, state and local government, agriculture, and geological exploration.

Important circumstances prompted the National Aeronautics and Space Administration (NASA) and the National Academy of Engineering to ask the SAB to consider a formal study of space applications. It had been six years since an earlier study, of the useful applications of earth-oriented satellites was completed by the National Academy of Sciences (NAS).<sup>\*</sup> The concern at that time was with obtaining considered reactions and recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program believed necessary to allow exploitation of earth-oriented satellites. This study provided valuable guidance for many space research and development programs which have now demonstrated the real potential of space systems.

Important advances had since been made in weather forecasting and in global communications through the operational use of satellites and their associated earth-based systems. In mid-1972, an experimental earth resources satellite was launched. Although designed for a one-year lifetime, it is still functioning. Designated LANDSAT-1 (formerly ERTS-1), it is equipped with scanning instruments that measure the brightness of points of the surface of the earth in two electromagnetic wavelengths in the visible part of the spectrum and two in the infrared. Data from such measurements can be used to construct images of the earth's surface or may be introduced directly into a computer for conversion to some other useful form of information.

For two and one-half years, more than 300 investigators, including many in other countries, have been experimenting with various practical uses of data provided by LANDSAT-1. The results of the experiments verify that many uses are possible. Other uses need further study, confirmation, or repetition under different circumstances to understand whether data collected for a limited sample of ground environments apply for other similar conditions.

It was clear to the SAB that it was now appropriate to ask a broad cross-section of users and potential users from commercial, industrial and regional organizations and from state and local governments what their needs were that might provide guidance for the development and practical application of future space systems. Thus, the SAB decided to devote the major portion of this new study to understanding the needs of managers and other decision-makers within the community of potential users of space information and services.

The SAB considered early in its planning whether the study should examine applications of space systems on an international scale. It was concluded that, in this first attempt, it would be difficult enough on a domestic scale to search out user needs and to relate them to the capabilities of space systems and that to broaden the scope to an international one would complicate the problem to an unwise degree. Thus, while the nature of the systems considered is such that it is inevitable that some comments on an international or global scale will be found in the report, the study is focused on domestic considerations.

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<sup>\*</sup>National Research Council. *Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

Under the general direction of the SAB, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth orbiting satellites. This work was done in July 1974 at Snowmass, Colorado. The Study Director was Governor Jack M. Campbell, President of the Federation of Rocky Mountain States and a member of the SAB. In the course of the study, the participants attempted to understand what impact space-derived data might have on the nature, the efficiency, and the effectiveness of user activities.

The study was organized around nine use-oriented panels whose assignments included reviewing progress in space applications since the 1967-68 NAS study and defining needs that might be met by data, information, or services derived from earth-orbiting satellites. User specialists, drawn from federal, state and local governments, from business and industry, and from the academic community, were grouped in the following panels: Weather and Climate; Uses of Communications; Land Use Planning; Agriculture, Forest, and Range; Inland Water Resources; Extractable Resources; Environmental Quality; Marine and Maritime Uses; and Materials Processing in Space. About 70 senior and experienced users -- for example, the chairman of a state land use commission, the Director of the Great Lakes Basin Commission, the vice president of a large agricultural business, the President of the American Institute of Merchant Shipping -- headed or participated in the work of the panels. The members of the panels are listed in Appendix II. Persons from interested federal agencies were also present at the study to provide consultation, background information and briefings to the panels as needed. These persons (among whom were a number of space technologists) are also listed in Appendix II.

A habitable laboratory, Spacelab, to be carried into space by the Space Shuttle, is being developed by the European Space Research Organization (ESRO) and will be an important element of the space program of the 1980's. Accordingly, the SAB invited ESRO to send to the summer study several representatives knowledgeable about Spacelab. The ESRO representatives, whose names are included in Appendix II, provided valuable technical help during the study.

Many members of the user panels began their deliberations with a good deal of skepticism regarding the usefulness of space systems in their particular field. Furthermore, prior to taking part in the study, many of the panel members had little knowledge of the information or services that satellites might provide. As the study progressed and the user panelists began to understand what had been accomplished to date in the practical use of space systems and to assess future possibilities, they began to perceive useful services that could be applied to their respective activities, whether in the private or the public sector. The users were then able to describe what information would be useful to them, and to describe some of the potential benefits that utilizing such information could have. The resulting dialog between the users and the space technologists made it possible for the users to express their needs in terms that were relevant to current capabilities or possible future capabilities of space systems.

The study also included panels on Information Services and Information Processing, Costs and Benefits, and Institutional Arrangements. It should be noted that the Costs and Benefits Panel was not asked to make detailed cost-benefit studies, but rather to indicate the circumstances in which such studies would be feasible and valuable, the fields in which they should be focused,

and in general, to provide recommendations that might lead to a better basis for making decisions concerning large investments in new space systems. Other panels assisted in assessing space transportation systems and the state of space technology.

The non-user panels employed, as a basis for their deliberations, needs expressed by the user panels. A substantial amount of interaction among the members of these panels and the user panels was designed into the study plan and was found to be both desirable and necessary.

As the study began, the Committee on Remote Sensing Programs for Earth Resource Surveys (CORSPERS) of the National Research Council was just completing a review of the usefulness of remotely sensed data for earth resource surveys and environmental monitoring. Dr. Arthur G. Anderson, Chairman of CORSPERS, participated in the study at Snowmass and provided draft copies of the CORSPERS report\* for use by the summer study panels.

The major part of the study was accomplished by the panels. The SAB has asked that the reports submitted by each panel at the end of the two-week study period be published as independent supporting documents. (For a list of the panel reports, see Appendix I.) While the SAB is in general accord with the panel reports, it does not necessarily endorse them in every detail.

Following the two-week summer study, the SAB reviewed the work of the panels, evaluated their findings, and prepared this report, which includes significant recommendations based on the work of the panels as well as conclusions and recommendations arrived at by considering the work of the study as a whole.

Information or services that might be derived from space systems may have application in many fields of human activity. Therefore, this report deals with a wide and diverse range of topics. The Board has not attempted in the report to make judgments of priority among the topical fields (such as agriculture, water, land use, the search for extractable natural resources), but rather has identified, to the best of its ability, two or three of the most important needs within each of these fields. The Board does not expect that all of the applications in the topical fields will be equally beneficial. In many cases, decisions and comparisons among them still remain to be made. The Board anticipates that in the normal processes of government, the Congress and the Executive Branch will make priority decisions in the course of allocating funds for these widely differing activities.

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\*Committee on Remote Sensing Programs for Earth Resource Surveys, National Research Council. *Remote Sensing for Resource and Environmental Surveys*. National Academy of Sciences, Washington, D.C., 1974.

## PUTTING SPACE CAPABILITY TO WORK

Some of the most difficult problems facing humanity today are concerned with assuring adequate supplies of food and energy, while at the same time improving and safeguarding the physical environment and the quality of life. Representatives of the user community present at the study were unanimous in their judgment that the Nation's capabilities in space should now be employed to assist in the solution of these problems.

This chapter summarizes needs, indicates accomplishments to date, and appraises future possibilities in the applications of space systems that the various user panels found promising.

### WEATHER AND CLIMATE

The use of satellites in the observation and prediction of the earth's weather represents one of the earliest of all space applications. It arose out of cooperation between the National Aeronautics and Space Administration (NASA) and the Department of Commerce (DOC). In addition to research and development leading up to and including launch of experimental satellites, NASA did much early experimental work in use of the images returned by satellites, both to explore technical possibilities and to engage the interest of potential users.

A basic agreement between the DOC and NASA concerning operational meteorological satellite systems, arrived at in 1964, dealt with the transition of weather satellites from the research and development phase to the operational phase as well as the operational phase itself. It established a basis upon which the National Oceanic and Atmospheric Administration (NOAA) could reimburse NASA for providing operational spacecraft and supporting technology for meteorological satellite development programs. Under this agreement, the TIROS series of research satellites was modified and made operational.

The SAB observes that the basic agreement between DOC and NASA has resulted in the implementation of many of the important recommendations concerning weather and climate made in the 1967-68 summer study on space applications. Other research and development activities recommended then have been incorporated into the Global Atmospheric Research Program (GARP) now in progress. The First GARP Global Experiment in 1978-79 will provide an intensive test of the applicability of the GARP systems to specific research needs and to prototype operational needs.



New needs are now apparent that are much broader than those expected to be addressed in the GARP observational experiment and can be expected to involve a much broader range of users than the weather forecasting community alone.

### Warnings of Hazardous Weather

In a 1971 report,\* the Committee on Atmospheric Sciences of the National Academy of Sciences placed a high priority on the development of comprehensive systems for monitoring prevailing weather conditions, with the information being made continuously available to broad categories of users. Input data might be derived from satellites and radar observations and from a network of low-cost, unmanned weather stations interrogated by computer. The combined output could be distributed to the general public and other users by television or other communication systems.

Prediction of local weather for periods of up to two hours is becoming increasingly important to the decision-making processes of a wide variety of users in the construction, agriculture, off-shore drilling and other industries. Additionally, the display of local prevailing weather is vital in alerting the public to impending disaster. Satellites offer a practical source of data for the timely display of present weather information and a possible vehicle for the rapid dissemination of warnings.

The wide demand for present weather data and the willingness of users to invest in the necessary receivers have been demonstrated by the extensive use of the Automatic Picture Transmission (APT) system, now part of the NOAA satellite series. Over 1000 users purchased or constructed specialized ground equipment in order to receive APT pictures. This represents a total voluntary expenditure of approximately \$10 million. Because this information is obtained from low altitude satellites, it is available at any given location about twice daily. The continuous flow of data that planned geostationary satellite systems could provide would increase manyfold the utility of present weather information. The requirement for rapid response essentially precludes centralized processing such as that now used for much other space-derived data. Many users will need low-cost receiving terminals of their own. An advanced geostationary satellite, with high resolution imaging and sounding capability (for which the technology is being developed), would permit such applications.

Accordingly, the SAB recommends:

*that low-cost ground read-out systems, suitable for use with planned geostationary weather satellites, having high resolution and sounding capability, be developed to permit observation of present local weather in real time so that users may obtain information rapidly about hazardous weather activity.*

\*Committee on Atmospheric Sciences, National Research Council. *The Atmospheric Sciences and Man's Needs: Priorities for the Future*. National Academy of Sciences, Washington, D.C., 1971.

## Long-Range Weather and Climate Predictions

Knowledge of weather and climate is essential in assuring adequate food supplies. Long range predictions are now receiving much attention and their importance justifies continued emphasis. Information from satellite systems, combined with earth-based observations, will make it possible to monitor on a long-term basis many of the physical factors considered by climatologists to be critical in establishing the mean or statistical state of the atmosphere for seasons, years or decades. Many of these factors are manifested in effects on the radiation balance of the land-ocean-atmosphere system. Included are the measurement of solar radiation, the determination of the earth's radiant energy retention capability (albedo), the measurement of outgoing infrared emissions, and the heat content of the mixed layer at the surface of the oceans. These measurements will ultimately be needed to relate the earth's energy budget to measurements of the state of the atmosphere such as the nature and the distribution of cloud cover and the vertical structure of temperature and humidity.

The SAB recommends:

*that to help provide a sound basis for long-range predictions of weather and climate, long-term observation be initiated of important long-term climatic factors such as the earth's incoming and outgoing radiations; the earth's albedo; the heat content of the mixed layer in the oceans; the distribution of clouds at low, middle and high levels; and any climatically significant changes in surface features such as vegetation, land use, and snow and ice cover.*

(It should be noted that the United States Committee for the Global Atmospheric Research Program has recently made a similar recommendation.\*)

## Other Uses of Weather Data

As a result of discussions with potential users at the summer study, the SAB has concluded that much of the information gathered by satellites for meteorological forecasters can also be used by other groups, if it is provided to such groups in suitable form and on a suitable time scale. Measurement and prediction of soil moisture, rainfall, snow and snow melt and run-off would be useful in agriculture and hydrology, for example. In the view of potential users, satisfactory institutional arrangements do not yet exist for involving, in the planning of programs for obtaining weather information, potential users outside the weather forecasting community so that their needs may be taken into consideration.

\*United States Committee for the Global Atmospheric Research Program, National Research Council. *Understanding Climatic Change*. National Academy of Sciences, Washington, D.C., 1975, pp. 67-68.



The SAB recommends:

*that potential user groups from outside the weather forecasting community be brought into the decision-making process of setting objectives and priorities for the development of new weather observing techniques, and for the processing, distribution and archiving of meteorological data, so that as wide as possible a spectrum of user groups can benefit from meteorological satellite systems -- now and in the future.*

#### LAND USE PLANNING

Recent years have brought a growing realization that land is a valuable resource, finite in amount, and that in the public interest there should be better planning of the manner in which land is used now and in the future. Some examples of concern are: whether land that is suitable for growing food should be used for that or for other purposes; whether sufficient land is being reserved for parks or other public uses; where to locate power plants with due consideration for the effects that the plant will have on the locality and for the needs of the plant, such as cooling water and access to fuel; the long-term effects of converting wet-lands to human use.

Land use planning involves a series of steps, including definition of the problem, acquisition of data relevant to the problem, establishment of goals and policies, implementation of a specific plan of action, and evaluation and monitoring of progress through the plan toward the goals. According to land use planners involved in the summer study, the limiting factor in this process at present is the timely acquisition of relevant data. The difficulties in acquiring adequate data are such that the establishment of goals and policies and the implementation of specific plans of action are often based on imperfect information, and evaluation and monitoring of progress toward the goals is done only superficially. Specifically, data gathered by current means have limited usefulness in the land use planning process because of incomplete coverage, inappropriate scale, poor reliability, or untimeliness.

Since the 1968 study, high altitude photographic techniques have advanced, and data from photographic sensors carried by aircraft are now being used to detect current land use patterns and to recognize changes in usage. High altitude photography has been employed by some regional planning agencies and county governments, but the use of aircraft to collect data for complete land resource surveys of whole states seems impractical for all but a few states because of the enormous amount of data that must be collected and analyzed and because repetitive surveys of large areas by aircraft are expensive.

An earth observation satellite is expensive too, but once launched it can pass regularly over most or all of the surface of the earth, observing the terrain under the same lighting conditions each time, for periods of years. Data from the LANDSAT series have been available to practical users for only two years, and there has not yet been accumulated enough experience in the use of the data to permit persuasive comparisons of costs or to permit conclusions about how spacecraft and aircraft can complement each other in the collection of land use (or other earth resource) data.

Experiments have shown that the sensors carried on LANDSAT-1 and -2 are adequate to provide data for preparing useful land use maps on a national, regional and state scale, and for determining where more detailed observations (from aircraft or the ground) are needed. LANDSAT (ERTS) data, both images and computer tapes, are being analyzed to provide land use information for certain states and large remote areas.

The potential for improving recognition of land use patterns by using the repetitive coverage given by LANDSAT has only begun to be investigated. LANDSAT images have been assembled into mosaics of the states of Florida, Wyoming, Michigan and New York, and the Washington, D.C. metropolitan area. The mosaics are being employed to introduce potential users to the information that can be extracted from LANDSAT data. LANDSAT data are beginning to be used by the U.S. Geological Survey (USGS) in cooperative programs with states.

According to land use planners, the one-acre resolution available from LANDSAT-type sensors is generally suitable for the majority of land planning uses. However, for about one percent of the U.S. land (principally in several hundred urban areas), the planners express a need to detect periodically areas set aside for parking, to observe traffic corridors, and to recognize cultural features having a size of  $10 \text{ m}^2$  to  $100 \text{ m}^2$  (this requires a resolution of 3 m to 10 m). While information of this kind could be collected piecemeal by cities using aircraft, it could also be collected for all cities from a single satellite if the ability selectively to focus on a small area were provided in the satellite sensors.

The Board believes that the ability to "zoom" is technically feasible and can be provided at a low additional cost on satellites that will be collecting earth observation data for other uses.

The Board recommends:

*that to meet the needs expressed by land use planners, the ability to observe selected regions with a resolution of the order of 3 meters to 10 meters be included in the planning of future earth observation systems.*

To permit more rapid and economical processing of remote sensor data for land use planning (and for most other uses, including agriculture and water resource planning), a key piece of technology is needed. Human photointerpretation of images is an expensive and highly specialized procedure. The process of extracting information from earth observations needs to be automated. The Board concludes that there is a need for the development of automated interpretation techniques and simple inexpensive equipment to permit more rapid and economical processing of remotely sensed data and hopes that the private sector will perceive this need and respond to it.

Automated extraction of information also requires that certain corrections be made to the data transmitted by the satellite, to compensate for such factors as instrument calibration and the sphericity of the earth.

The Board accordingly recommends:

*that geometrically- and radiometrically-corrected digital tapes of earth resources satellite data be prepared as a matter of routine and made readily available to users.*

Land use planners involved in the study have expressed a need for emphasis on remote sensing research and development focused on the following three key areas:

monitoring changes in land use patterns;

periodically surveying power plant sites, mining sites, coastal zones, wildlife habitats, geologic hazards, oil pipelines, and other areas where the use of the land may affect the environment; and

determining the capability of land to support proposed new uses without violating environmental, economic or esthetic standards.

It may be expected that by the early 1980's, operational satellites will be supplying earth observation data for agriculture, hydrology, marine activities and other fields. It should be possible to meet the needs of land use planners for monitoring land use changes, inventorying critical environmental areas, and assessing land capabilities if steps are taken now to assure that those needs are taken into consideration in the design of the satellites.

The Board recommends:

*that the needs expressed by land use planners to detect changes in land use, make detailed periodic surveys of areas where the use of the land may critically affect the environment, and determine the capability of land to support proposed new uses, be taken into account in the design of future earth observation satellites.*

National land use planning legislation introduced in the 93rd Congress, if it had been enacted into law, would have encouraged all states to establish land use planning programs.\* Most of the proposed laws would place upon the states the burden of preparing inventories of how land is currently being used. In addition, implementation of the laws would require analyses of uses to which land is suited, continued monitoring of land use, and coordination of land-use-associated activities on a state, regional and local basis. Land use planners involved in the study estimated that it would cost the states, regional authorities and cities approximately \$250 million per year over the next decade if conventional means were used for collecting land use information. The SAB believes that remote sensing systems could supply much of the necessary information in more timely fashion and at significantly lower cost, and that future federal land use legislation should recognize that possibility.

Accordingly, the SAB recommends:

*that any new federal land use legislation (and state legislation, if it is affected by federal standards) take into*

\* U.S. Senate S. 268 and U.S. House of Representatives HR. 10294, 1973.

*consideration the possibilities of acquiring data by the use of remote sensing from aircraft and space.*

#### •AGRICULTURE, FOREST, AND RANGE

The results of analyses of LANDSAT-1 data by about 300 experimenters point to many uses in the inventorying and monitoring of major crops, forests and rangelands, not only on a local basis but on a regional and even a world-wide basis. Some of these uses have been verified; others need confirmation or repetition under alternative circumstances to assure that data collected for a limited sample of ground environments applies in other similar circumstances. Some of the experiments have been clearly successful. These include:

- identification of crops and of broad types of forest and range-land vegetation;

- identification of broad soil and land use patterns in agricultural areas;

- experimental detection, on a limited scale, of severe crop and forest damage due to stress (insects, disease, drought, flood and fire);

- estimation for small test plots of wheat acreage, yield, and production by use of satellite data in conjunction with a yield model incorporating meteorological data;

- monitoring progress of crop harvests in small trial areas;

- identification of vegetative biomass in rangelands, permitting evaluation of range conditions;

- determination of irrigated acreages; and

- monitoring irrigation reservoirs and livestock water impoundments.

Originally, few of the investigators had the equipment necessary to use computers in their analysis of the digital tapes containing LANDSAT-1 data. Many of the above experiments were performed by visual interpretation of the reconstituted images. As experience was gained with data processing, computer-assisted statistical analysis of the digital tapes containing multispectral scanner data emerged as the preferred method for extracting maximum quantitative information. Computer-assisted digital analysis has also permitted comparison of the data from each picture element (representing about one acre on the ground), recorded in successive passes of the same satellite over the same area. This allows recognition of changes with time, which in many cases is essential to the identification or monitoring process. Other users will be utilizing data from passes of different satellites over the same area. For the latter

users, radiometric and geometric correction of the data is required so that temporal overlays can be made, picture element by picture element. Users state that presently available equipment for this purpose is specialized and costly. The Board concluded earlier in this report that inexpensive equipment is needed and expressed the hope that the private sector will perceive this need and respond to it.

According to agricultural users involved in the study, some of the information needed in agricultural management must be provided to the user within 3 to 5 days after the satellite acquires the data. As a matter of fact, the ultimate objective of data acquisition or generation is its constructive utilization in the attainment of socially beneficial and economically productive ends, and many users need data more rapidly than the present means for disseminating data can supply it. The Department of the Interior's Earth Resources Observation System (EROS) Data Center was intended to be an experimental, off-line system. The SAB believes the Center has been very successful in achieving the goals established for it. However, the whole process of extracting information, converting it to the form in which it is needed by the user, and getting it into the user's hands now needs to be speeded up significantly.

The Board recommends:

*that the successful experimental off-line processing system at the Department of the Interior's Earth Resources Observation System (EROS) Data Center and the procedures for transmitting information to the users be modified so that information reaches users, in the format they need, within 3 to 5 days. It is further recommended that this capability be developed in time to permit its use with LANDSAT-2 so that pre-operational experiments can be conducted.*

#### An Agricultural Experiment

The results of LANDSAT-1 experiments suggest that multispectral data can be used, with supplemental weather and ground observation data, to prepare a crop inventory. Since the summer study meeting, a wheat inventory experiment, the Large Area Crop Inventory Experiment (LACIE), has been agreed upon by the U.S. Department of Agriculture (USDA), NASA, and NOAA, and work has begun to try to inventory a significant fraction of the world wheat crop using LANDSAT-2 data and certain USDA ground observations, together with NOAA weather information. Results of this experiment should provide valuable information and experience to guide the planning, design, and implementation of future operational remote sensing systems. Properly planned, it can also provide the basis for estimating costs and benefits of an operational system.

Accordingly, the Board recommends:

*that in view of the urgent need for better information on the world food supply, the Large Area Crop Inventory Experiment (LACIE) be expedited, and that the resulting experience be utilized for planning, design and implementation of an operational system; and*



*that the overall LACIE plan provide explicitly for observation of those parameters needed for cost and benefit estimates which would serve as part of the basis for deciding whether to proceed with an operational system.*

The advisability of measuring parameters related to costs and benefits applies to other experiments as well, and the Board makes a general recommendation on the subject in a later section of this report dealing with benefits and costs.

#### Continuity of User Experiments

As a result of discussions with various groups over a period of time, the SAB has concluded that state agencies, federal and regional agencies, and private enterprises having interests in land, food, and fiber resources have been reluctant to invest in serious experiments in the use of data from satellites because up to this time there has been no guarantee of continuity of data flow or of continuity in the format of data products.

This conclusion was reconfirmed in discussions at the summer study. The present LANDSAT-1, having functioned well beyond its design lifetime, is now backed up by LANDSAT-2, launched in early 1975. Just recently, NASA has been authorized by the President to include in the budget for fiscal year 1976, funds necessary to begin work on a third earth resources technology satellite, LANDSAT-3. If funds for LANDSAT-3 are provided by the Congress and the project proceeds, an important step will have been taken toward assuring potential users that they may expect a continuing flow of data.

The Board recommends:

*that, to assure continuity of data and to assure progress toward an eventual operational system, LANDSAT-3 be developed, and that plans proceed to launch it as a follow-on to LANDSAT-2.*

(It should be noted that the NRC's Committee on Remote Sensing Programs for Earth Resource Surveys reached a similar conclusion in mid-1974.\*)

#### INLAND WATER RESOURCES

Water quality and water use data are collected throughout the Nation by many agencies for use in water resource management and operational programs. The amount of detail needed varies over a wide range. For reconnaissance studies, general characteristics are adequate. On the other hand, a detailed water quality monitoring program requires an accuracy that can be obtained only with *in situ* sampling and laboratory analysis. It should be noted that

\*Remote Sensing for Resource and Environmental Surveys, 1974, pp. 22-23.

too much detail, where not needed, can cause as much difficulty as insufficient accuracy, where accuracy is important..

### Water Resource Management

According to water resource managers involved in the study, satellites can help in two different ways to provide data needed for management of water resources: (1) through real-time sensing from space, and (2) by collecting data transmitted to the satellites from instruments, emplaced on water or on land (*in situ* sensors), and relaying the data to central collection points on the ground. Rapid assessment of the danger and dissemination of warnings for floods and other storm hazards are needed. Real-time information on rate of precipitation, snow cover, water content and rate of melt, and soil moisture are essential to operate flood control systems and to provide hazard warning.

Reservoir operators require forecasts of storm and seasonal runoff to control storage space for agricultural use, flood control, generation of hydroelectric power, and conservation of water supplies. Long range (three months), medium range (one week), and short range (two days) forecasts of runoff would all contribute to better reservoir operation.

Real-time information is also needed for water pollution monitoring and control. Knowledge of water quality parameters is essential to implement many water-quality and pollution-control programs.

### Development of *In Situ* Sensors

Several satellites already in orbit, including LANDSAT-1 and -2 and the Synchronous Meteorological Satellite (SMS), have data collection capability. The SMS alone is capable of interrogating some 10,000 platforms. However, according to water resource managers, ground sensing stations for collecting water data are at a relatively early state of development, and only a small part of the satellite data collection capability that exists today is being utilized. More rugged equipment, which can survive severe weather, efforts at vandalism, and environmental contamination for periods of at least six months to one year, must be developed. This is almost entirely an engineering problem and should be solvable, but present equipment cannot meet these needs. It must be noted that it is primarily agencies of federal, state, or local government that pay the costs of data collection, and that these users of *in situ* instruments are not perceived as an attractive and aggregated market by those who might manufacture better instruments.

If adequate *in situ* sensing stations were available, satellites equipped with data collection systems could provide data on many of the needed parameters. These would include measurements of ice and snow water content, subsurface water, the dynamics of surface water flux, and most of the water quality and environmental parameters. At present, laboratory techniques are available for sampling and monitoring and in most cases the techniques are standardized. Present *in situ* sensors, however, cannot duplicate the laboratory analysis required for the detection of many water quality parameters and require in-place equipment that impedes navigation or other water use.



Conventional ground communications by radio are inhibited by two factors: first, radio spectra are extremely crowded at low frequencies; second, higher frequencies are limited to line-of-sight communication and thus are not practical in remote areas and in rugged terrain. Many practitioners who collect data from *in situ* sensors now do so by radio from high flying aircraft. Their choice of this mode takes into consideration the cost of this means compared to conventional ground communications.

To take advantage of the capabilities of space or airborne data collection systems will require the development of accurate automated ground stations which can operate for long periods of time without requiring maintenance or repair. Their information output could be relayed by satellite or aircraft without the need for human intervention, thus permitting coverage of many more locations -- some of which may be remote and difficult to serve -- than could be afforded if the stations had to be tended by permanent monitoring personnel.

The Board recommends:

*that NASA, the Environmental Protection Agency, and the Department of the Interior collaborate to assure that a vigorous development program is undertaken to provide vandal- and environment-proof water-parameter monitoring ground stations suitable for use with satellite and aircraft data collection systems.*

#### Development of Remote Sensors

Measurement of some important water resource parameters from space is difficult, and it is doubtful that complete independence from ground stations can ever be achieved. However, some parameters can be sensed directly, and others can be inferred. For example, the depth of groundwater reservoirs below the surface can be estimated by observing the kinds of vegetation growing on the surface. Some deep rooted plants feed on the water table, and these might be observed from space. The large area coverage offered by measurements from space has been shown to be valuable in other disciplines, and satellite-borne sensors should prove more cost-effective than ground stations where their use is technically feasible for water resource management.

The Board recommends:

*that federal research and development programs for spaceborne sensors of water resource parameters be given greater emphasis. Work should be directed at developing the capability to measure directly from space the area and, indirectly, the depth of groundwaters.*

#### EXTRACTABLE RESOURCES

Important minerals are rare and difficult to find. The extractive industries use every available technique to aid in their searches. While the companies involved are reluctant to divulge how and to what extent they find

LANDSAT data useful, approximately half of the sales of information products (images and tapes) provided by LANDSAT-1 have been to the extractive industries. This is particularly noteworthy in view of the fact that these users are only beginning to learn how to use LANDSAT data to their full potential.

Improved weather information provided by the Weather Service from the NOAA operational weather satellite system is of great value to the extractive industries. Field camps, mines and drill sites are frequently located in remote and primitive environments, where local weather data are scant. Short term weather forecasts are crucial to the safety and success of the operations involved in exploration and extraction. The industry expects the importance of improved weather information to increase, especially as off-shore mining and oil drilling activities move farther from shore and to deeper water. The extractive industries, then, have a strong interest in the results of ongoing research programs for improving weather observation from space and for achieving better short range and long range weather forecasts, as recommended earlier in this report.

A Navy navigational satellite, TRANSIT, has been used by the extractive industries for navigation and position location. With it, exploration crews working in remote and poorly mapped areas have been able to determine their positions within about one quarter of a mile. Marine seismic crews have used satellite navigation, using inertial guidance or bottom-reference sonar to interpolate between satellite fixes. Some companies have developed their own portable ground stations to permit them to use satellites to locate base camps or other fixed installations.

Exploratory geologists involved in the study pointed out that exploration crews need to locate field sites (especially in remote areas lacking surveyed benchmarks) to an accuracy that will permit them to establish property boundaries and emplace claim stakes. In the judgment of the exploratory geologists at the study, a position-determination capability of  $\pm 30$  m (100 ft) is required.

The Department of Defense (DOD) is now taking the first steps toward establishing a global space-based position-determination system which it appears will have an accuracy better than  $\pm 30$  m. If this system (known as the Global Positioning System or NAVSTAR) is eventually placed into operation by the Department of Defense, and if it is made usefully available to the civil sector, it would offer a great improvement in coverage and accuracy over existing systems. However, to assure that such a system satisfactorily meets both U.S. military and civil needs may require the development of new and sophisticated transmission equipment and computation techniques. Although it is the present intention of DOD to make the system available to civilian users, deliberate and visible policy decisions will have to be made by the Executive Branch at a reasonably early date if the aerospace and electronics industries are to have a useful appreciation of those operational and other factors that they must have to consider whether they should invest in the development and marketing of low-cost terminals for non-military use.

The Board recommends:

*that the Office of Telecommunications Policy, the Department of Defense, and others as appropriate seek an early formal Executive Branch policy decision concerning civil use of the*

*Global Positioning System, and establish those formal administrative mechanisms required to assure that the development of the system takes into consideration, to the extent possible, the needs of civil users.*

The extractive industries are potentially important users of operational satellite communication systems. Voice communication, worldwide, is a continuing need for these users. Data transmission by satellite will open up new possibilities for crews operating far from central laboratories. Geophysical crews, working on land or aboard ships, collect very large quantities of data and need to communicate these data, at a rate as high as ten million bits per second, to central computers. While this bit rate is within the capability of present satellite communications systems, very large (and expensive) ground terminals are necessary to use existing satellites. A system which can be used with small, low-cost earth terminals for field use and the associated small terminals are needed.

The SAB recommends:

*that performance requirements for a communications system be specified by the extractive industries, so that these requirements can be taken into consideration by the private sector in the design of future satellite communication systems.*

LANDSAT images completely free of clouds are now available for every part of the United States. The data have been used extensively to detect lineaments and other geological signatures associated with mineral occurrences. For example, a large scale mosaic covering several states, including Utah and Colorado, has revealed some previously unrecognized details of an east-west fault associated with the Colorado mineral belt. Known mineral locations correspond with those deduced from LANDSAT-1 data, indicating the possibility that recognition of other lineaments may reveal other areas warranting exploration. It is known that there have been important successes in locating new mineral deposits with the help of LANDSAT data.

With all of the successes and the knowledge gained from LANDSAT, it is still an early experimental system. Improvements and advances in temporal and spectral coverage are needed. Thermal measurements are needed. A thermal infrared sensor is under development for LANDSAT-3. The Board believes that this sensor will help importantly in identifying earth surface features.\*

Some regions of the earth where there may be deposits of oil, gas or minerals are covered by clouds most of the time. Extension of spectral coverage to the microwave region would permit observations even with cloud cover.

The SAB recommends:

*that the vigorous research and development program in new remote sensing techniques be continued by NASA, that the*

\*The Committee on Remote Sensing Programs for Earth Resource Surveys reached the same conclusion (see *Remote Sensing for Resource and Environmental Surveys*, 1974, pp. 23/24).

*thermal infrared sensor be added to the multispectral scanner on LANDSAT-3, and that, to permit observation through clouds, emphasis be given to the development of microwave sensors.*

The identification of new regions likely to have minerals or oil and gas deposits is based on the accumulated wisdom of generations of previous investigators whose work has developed extensive knowledge of the earth and has led to the development of theories of origin of mineral deposits. In the opinion of geologists involved in the study, the synoptic view of the earth's surface obtained from remote sensing devices on satellites and on aircraft can make valuable contributions to this knowledge and theory.

It has been asserted that the extractive industries are one-time users of remote sensing data; that is, one view of a particular region of the earth is claimed to be sufficient to assist in the discovery of minerals. This is not correct. The image of a region is highly influenced by seasonal changes in vegetation, snow cover, moisture content, lighting and solar heating. Important subsurface features may be deduced from differences in the appearance of the surface that accompany such seasonal changes. Some work is under way using experiments on LANDSAT to understand this process, and additional work is needed.

The Board recommends:

*that NASA, in consultation with the extractive industries, vigorously pursue experimental use of LANDSAT to determine the effects of seasonal change on images of the earth and to assess their usefulness for assisting in the discovery of minerals, oil and gas.*

It is unlikely that any single sensor can locate individual mineral deposits directly. However, geologists involved in the study expressed the view that better definition of the relative motion of tectonic plates (estimated at 1 cm to 10 cm per year) can contribute to understanding of the metallogenic process and may disclose new regions that merit detailed exploration. Plate motions are irregular. Measurements may be needed annually for a decade or, in localities of special interest, as frequently as hourly for periods of weeks. Statistical data reduction processes will need to be used. To define relative motions, a system should be capable of providing individual measurements of the displacement of the earth's major tectonic plates to an accuracy of  $\pm 3$  cm. Several experiments now under way have given preliminary indications that the required displacement accuracy may be attainable. One experiment involves laser ranging to satellites from points, widely separated, on each of two adjacent tectonic plates. The range data can be processed to yield the relative displacement of the points. Another experiment uses very long baseline interferometric tracking of radio stars. Here again, the data can be processed to determine the relative displacement of the tracking sites, located on each of two adjacent tectonic plates.

It should be noted that the same observations are needed by geophysicists to gain more understanding of the mechanisms of earthquakes and possibly to help produce a future earthquake warning system.



The SAB recommends:

*that to improve understanding of the process by which minerals are deposited near the earth's surface, emphasis be placed on research and development programs related to earth physics, including the development of systems that can measure the relative displacement of tectonic plates to within  $\pm 3$  centimeters.*

## ENVIRONMENTAL QUALITY

The earth is now recognized essentially as a large spacecraft whose self-contained environment must be maintained by wise management of its food, fiber, water, air, mineral and other natural resources. Real-time knowledge of man's interaction with his environment is essential. There is major concern that the environment is being adversely affected by man in the course of extracting coal, natural gas and petroleum from the earth, converting these non-renewable resources to energy, and using the energy. In addition, the growth of the earth's population, the tremendous increase in industrial activity, and the concentration of people in cities and expanding metropolitan areas have brought major problems in maintaining the quality of the physical atmosphere and an adequate supply and quality of water.

It may be expected that the per capita consumption of energy in the industrialized nations will continue to increase. The aspirations for comparable standards of living -- and hence energy demands -- of the less developed nations will bring even greater efforts in the future to extract the remainder of the earth's dwindling supply of non-renewable fuels. Environmental concerns include protecting the land and sea areas from which fuels are extracted, protecting the land, air and water resources involved in the processing of fuels, and minimizing the adverse consequences of man's activities associated with the use of energy.

Laws recently enacted at the federal and state levels, together with action programs at the federal, state and local government levels and by industries, are moving the Nation at an accelerated rate to a cleaner physical environment. An implementation schedule has been established that calls for most of the goals to be met within 10 years.\* It has been estimated by environmental specialists involved in the study that in excess of \$100 billion will be spent during the next decade for pollution control.

In the course of the study, a review of the needs of major users of environmental quality data and of recent progress in environmental quality programs identified specific areas where current and evolving space technology could contribute to achieving national environmental goals. In recognition of the need for environmental quality monitoring, the Environmental Protection Agency (EPA) and NASA have been conducting cooperative programs to apply space technology to meet certain user needs in the environmental area. Substantial

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\*Clean Air Act of 1970 (PL 91-604) and Federal Water Pollution Control Act Amendments of 1972 (PL 92-500).

progress has been made in developing sensors and systems for air quality monitoring in the stratosphere. In contrast, however, progress in developing sensors and systems for monitoring the lower atmosphere and monitoring water quality is lagging. There is an immediate need to use state-of-the-art technology and to place in operation improved and expanded air and water quality monitoring programs to meet regulatory requirements.

The need for and the opportunity for the application of more cost-effective solutions to pollution control problems are greatest today and in the near future, although there will always be a need for improved solutions. In the opinion of the SAB, for space technology to have a significant impact on the pollution control program, the timetable of the effort related to environmental quality monitoring must be greatly accelerated. The space applications program, as currently planned, is not moving ahead rapidly enough to have a major impact on this monitoring program.

Accordingly, the Board recommends:

*that immediate steps be taken to make full use of currently available space techniques and systems in monitoring the environment, using both in situ and remote sensing instruments. It is further recommended that those elements of the space applications program which show promise of helping to fulfill regulatory requirements related to the environment be substantially accelerated.*

The troposphere is the lowest major layer of the atmosphere, and extends from the earth's surface to a height of about 12 km. It is in this lower layer of the atmosphere that most of the important processes affecting atmospheric pollution, as well as weather, occur. Most of the first-order effects of airborne pollutants experienced by man, plants, and animals are highly dependent upon the dispersion and dilution capacity of the troposphere. A temperature inversion layer just above the troposphere acts to some extent as a cap or lid on the mixing layer. The most immediate air quality problems involve sensing and controlling the pollutants in the layer of the troposphere nearest the earth.

Accordingly, the SAB recommends:

*that a vigorous program be mounted, using sensors on the earth's surface, in aircraft and in spacecraft, for monitoring the troposphere to assess on both regional and global scales the impact of air pollution and of air quality control. Specific needs include the development of capabilities for all-weather, day and night measurements, and sensors to measure the vertical distribution of pollutants from the ground up.*

The stratosphere is the region of the atmosphere from about 12 km to 50 km above the surface of the earth. The stratospheric ozone layer filters out ultraviolet radiation from the sun that is harmful to most forms of earth life. There are growing concerns about the potential for effecting significant changes in the worldwide climatic conditions through the introduction of both trace gases and particulates into this protective barrier of the planet. Several

basic properties of the stratosphere make it sensitive to the injection of trace gases and particulates of both man-made and natural origin. The photochemical processes that determine the ozone content are not well understood. It is conceivable that the introduction of new materials or the increase in quantity of chemical forms leading to new equilibrium values could significantly alter the protective ozone barrier.

Pollutants can be injected into the stratosphere by exchange of air between the stratosphere and the troposphere. The effects of this natural phenomenon conceivably may be modified as the pollutant load at the boundary between the troposphere and the stratosphere increases or changes in character. Man has already introduced materials into the stratosphere as the result of weapons testing and flights of aircraft at high altitudes. Residence times of these materials in the stratosphere and fallout patterns attest that exchanges do occur between the stratosphere and the troposphere.

The SAB recommends:

*that emphasis be given to plans for monitoring the environmental quality of the stratosphere on a global scale. The first need is to make baseline measurements of stratospheric species, both gases and aerosols, with emphasis on the species involved in ozone chemistry. Follow-up measurements should be directed at determining the impact of man-made pollutants on significant stratospheric natural processes.*

(It should be noted that similar recommendations have been made by groups concerned with the effects of aircraft flight at high altitudes.\*)

#### MARINE AND MARITIME USES

The areas of possible application of space systems to marine and maritime uses include better understanding, control and use of the oceans' biological and physical processes and the provision of technological aids that will improve the efficiency and enhance the safety of maritime operations. According to representatives of the maritime community involved in the study, three general areas should receive major attention: monitoring of the marine environment, communications, and position determination.

\*A. J. Grobecker, S. C. Coroniti and R. H. Cannon, Jr. *The Effects of Stratospheric Pollution by Aircraft: Report of Findings*. Climatic Impact Assessment Program, Department of Transportation, Washington, D.C., 1974, p. 114.

Climatic Impact Committee, National Research Council. *Environmental Impact of Stratospheric Flight*. National Academy of Sciences, Washington, D.C., 1975, p. 34.



## Monitoring of the Marine Environment :

The increase in human activity on and near the oceans and the increasing dependence on the seas as a source of protein has led to an increased need to monitor and forecast the behavior of this part of our natural environment and to manage human activities conducted upon it. It was the conclusion of maritime users involved in the study that satellites could make an important contribution toward fulfilling these needs by supplying data on which forecasts and management depend.

User needs for satellite data related to marine activities have been well expressed by previous studies of the National Academy of Sciences, the National Academy of Engineering, NOAA, the U.S. Coast Guard, and the SEASAT User Working Group. The ability to meet these needs, however, is still in the future. Many of the instruments capable of making the desired measurements are still being developed. The first ocean monitoring satellite, SEASAT-A, is planned for 1978, and an ocean color sensor is planned for NIMBUS-G in that same time period.

The most immediate and pressing goals expressed by the marine community include:

- better forecasts of wind, waves, ice and storm hazards, both at sea and along coasts;

- improvement of fisheries through better monitoring of biological productivity and the physical variables upon which this productivity depends; and

- improved management of man's activities in the near-shore zone.

The instrumentation planned for SEASAT-A includes an altimeter, a scatterometer, an ultra-high frequency radiometer, a microwave polarization radiometer, an infrared imager, and high spatial resolution radar imagers. This ensemble of instruments will permit the collection of wind data, wave spectra, wave refraction, and data on currents and parameters of the geoid, and will provide research and development data needed to permit substantial advances in physical oceanography.

The Board recommends:

*that the SEASAT-A and NIMBUS-G programs be vigorously pursued. Their measurement products are critically needed in understanding processes of the oceans, including those processes related to ocean productivity.*

## Maritime Communications

Much of the research and experimentation related to maritime communications recommended in the 1967-68 study has been completed. Extensive maritime communications experiments have been conducted using the ATS series of satellites.

An operational maritime satellite communication system (MARISAT) will be available for use in the Atlantic and Pacific oceans in mid-1975. While there are some limitations in MARISAT's initial capability because of terminal equipment cost and size, it will provide continuous operational communications services between 70° N and 70° S latitude except in the Indian Ocean and an area off the west coast of Mexico. It was the opinion of maritime users involved in the study that complete coverage in that part of the globe lying between 70° N and 70° S latitude is needed at the earliest possible time. In the 1980's, it is expected that the search for fuels, minerals and fish in the polar regions will be intensified, and it will then become necessary to extend the system of maritime communications to reach the polar regions. It should be noted that maritime communication services are provided by the private sector, which must perceive a market before making an investment to provide the service.

The early service provided by the operational MARISAT system is expected to be adequate. However, shipboard equipment that can provide the improved communications offered by satellites is expensive. Until the cost can be sharply reduced, a very wide community of users of small ships (and boats) may not be able to afford improved (and adequate) communications. A more sophisticated spacecraft, while allowing a less sophisticated terminal, costs more than a less sophisticated spacecraft, but it also allows many more users to partake of the spacecraft-related services, thus spreading the overall system cost over a larger number of users. To reduce the size of shipboard antennas and the cost of other shipboard equipment will require that satellites radiate more power.

*The Board concludes that, if economies are to be achieved in shipboard equipment, emphasis will have to be placed by the private sector on research and development directed at increasing the effective radiated power of maritime communication satellites. The Board believes that when the power radiated by communications satellites is increased, industry will develop lower-cost and simpler shipboard terminals.*

#### Position Determination

A number of ground-based position determination and navigation systems are currently operational. Each has been developed to meet some special need or to serve some region, and for each there are limitations in coverage, availability or accuracy. The present proliferation of terrestrial position-determination systems, no one of which is completely adequate, results in a dissipation of public and private funds, necessitates carrying aboard ships and aircraft different devices for navigating in various parts of the world, and wastes valuable segments of the already over-crowded electromagnetic frequency spectrum. A unified system is needed to meet maritime user requirements. It should be noted that the requirements of the maritime community for position determination might be met by a system meeting the requirements, discussed earlier, of the extractive industries.

The 1969 NAS report recommended that a space-based system be implemented to demonstrate operational feasibility and to find ways to reduce costs. (The Navy satellite navigation system -- TRANSIT -- is available for civil use and provides global coverage, but its accuracy is limited to about one-quarter of a

mile and the procedure for using it is complicated and requires costly shipboard equipment.\*) Experiments since the study have shown the feasibility of several techniques for position-determination using satellites, and have provided a limited opportunity for users to see how they may beneficially use, in their operations, more precise position determination. In the Board's opinion, the need now is to conduct system demonstrations to permit users to gain more experience so that they may better specify their requirements, and to permit the suppliers of shipboard equipment to evaluate the market.

The Board recommends:

*that a joint government-industry user demonstration of position-determination using satellites be conducted; of sufficient duration to permit a variety of maritime users to gain experience needed for them to specify their requirements.*

In the view of the representatives of the maritime community involved in the study, there is at present no effective means by which the many potential maritime users in the United States can aggregate and express their needs for position-determination services and facilities. Neither is any international body available to provide worldwide coordination for position-determination system development and implementation. These factors have inhibited the innovative solutions which appear to be necessary to meet user needs.

The Board recommends:

*that the responsible federal agencies encourage leading organizations in the maritime community, building on their cumulative experience gained from satellite position-determination demonstrations, to collaborate in specifying performance requirements needed for a maritime position-determination system.*

#### SOME SPECIAL CONSIDERATIONS CONCERNING SATELLITE TELECOMMUNICATIONS

At the time that the report of the NAS study of space applications was published in 1969, the Communications Satellite Corporation and INTELSAT had

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\*To gain the maximum accuracy from a single pass of the TRANSIT satellite (about 40 m), the velocity of the ship must be accurately known. A velocity error of one knot in the worst case (east-west direction) degrades the position-determination accuracy to about 400 m. Ocean currents of several knots are commonly encountered by ships, but it may not be possible to measure them accurately enough to reduce position errors to an insignificant level.

The system accuracy degrades from 40 m to about 200 m during ionospheric disturbances. This error can be essentially eliminated by using a shipboard terminal able to receive and analyze signals at two radio frequencies. Equipment for civil users is available at a cost of about \$30,000 for a single-frequency terminal or about \$50,000 for a two-frequency terminal. These costs could be reduced by about one-third if there were a market for large numbers of terminals.

been in business for five years; interim international working arrangements had been arrived at, and a basic international satellite communications network had been established. INTELSAT III, with a capacity of 1200 voice circuits, was soon to be launched. The need for, and the character of, a United States domestic satellite communications service were being debated. The NAS report drew attention to the possibility of using satellite repeaters to distribute television programs domestically and to relay meteorologic, oceanographic and hydrologic data from many surface and near-surface stations, some remotely located, where human access would be difficult. The report also pointed out the possibility of developing much more sophisticated satellite and surface station technology, and emphasized the necessity to explore the use of spectrum regions higher than the 4 to 6 GHz regions then in use.

The past decade has seen a total of 86 countries join the international satellite communications network and definitive agreements worked out for INTELSAT; establishment of thousands of voice circuits in this global network, accompanied by a marked reduction in costs to the public for overseas telephone calls; and widespread international distribution of television, especially for sports events and news coverage. The possibility of a single satellite that would permit establishing tens of thousands of voice circuits is being actively explored. A policy providing for competitive domestic satellite communications has been established. Domestic satellites have been recently launched to serve the United States and Canada and many circuits are already in service. Several other countries are exploring the establishment of national and regional systems. A series of Applications Technology Satellites has been launched and their uses studied, culminating in the ATS-6, which has been used for early experiments in education and health service delivery. Plans are actively under way to use satellite repeaters to improve maritime and aeronautical communications.

The recent past, then, has seen an impressive series of accomplishments in the satellite communications area -- accomplishments that have realized much of the promise outlined in the 1969 NAS report. But all of the important goals set forth in that report have not been attained, and it would be incorrect to judge that further accomplishments are either relatively unimportant or unachievable -- far from it.

In addition to the specific examples of needed and possible advances in communications services suggested earlier in this report, it should be appreciated that appropriately designed and established domestic satellite communications circuits could widen the distribution and reduce the cost of reliable common-carrier voice, data and television communications services throughout the country generally and improve service for those regions where there is relatively low population density, difficult terrain, or difficult climatic conditions. Mobile services, which currently represent a multimillion dollar a year market in the United States, could also be improved. The effectiveness of air-sea rescue operations could be significantly improved. Appropriate satellite communications networks could also assist importantly in the Nation's growing environmental monitoring activities by relaying data gathered by large numbers and varieties of remotely located surface and near-surface sensors.

The possibility of using satellite communications circuits to speed and ease the delivery of mail, to improve access of remote areas to cultural activities and certain education and health services, to improve methods of warning

of natural disaster, and to distribute time and frequency signals to regions of the earth where conventional radio does not provide adequate service all appear to hold promise and should be explored further.

It may be expected that many of the next important applications of satellite communications will be in the public area -- applications that would see the provision of new public services or of important cost reductions or cost avoidances in the delivery of present public services. Adequate technical and economic exploration and testing of such services, however, will take considerable time and money, perhaps will require markedly different technological approaches than those now in hand or being developed, and may not be easily accommodated in all cases by the Nation's present common carrier network. Further important progress will take place at an early moment only if certain difficulties that now inhibit broadened uses of satellite communications are appreciated and steps taken to minimize them.

The extraordinary commercial success of satellite communications in the past decade has led some to conclude recently that all further required progress can be left to private industry alone. Certainly, the private sector will exploit and refine the present technology, and will improve the efficiency and, in time, the quality of services currently provided. But the private sector can do so only at a pace dictated by its own perception of the character and size of the markets and in a manner consistent with present investments, capital resources, and the present character of the aerospace and communications common carrier industries. Consequently, the private sector will find it difficult -- perhaps even impossible in the near term -- to support major sophisticated technological advances, especially when the technological risks are great, when the eventual markets are not clear, when only the broad public good is involved, or when the present institutional and regulatory framework does not easily respond to new service needs or new technological approaches. Under these circumstances, it is the Board's belief that, unless NASA resumes its role in advancing the technology of satellite communications, there is a danger that this country could lose important opportunities and possibly forfeit its position of technical leadership in this field. Further, NASA has a statutory role\* in satellite communications technology, and performance of much of this role requires that NASA maintain its capabilities in satellite communications research and development.

The Board recommends:

*that NASA, with the active encouragement and assistance of the Office of Telecommunications Policy in the Executive Office of the President, maintain a broad and vigorous satellite telecommunications technology development program. This*

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\*Under Sec. 201(b) of Public Law 87-624 (the Communications Satellite Act of 1962), NASA is required to advise the Federal Communications Commission on technical characteristics of the communications satellite system, cooperate with the Communications Satellite Corporation in research and development, and consult with the Communications Satellite Corporation with respect to the technical characteristics of the communications satellite system.



*program should be one that will allow NASA to continue to discharge its statutory national advisory role in this area and to assure that technological advances are made which may be beyond the ability of private sources to support but that either protect the broad interests of the general public or offer promise of generating new or improved telecommunications markets or services.*

Many of the telecommunications services envisioned for the future would be enhanced, expedited, and made more generally available if user terminal equipment were small, lightweight, and easily operated and maintained by non-technical people, and the service costs were low. Achieving these ends may well require the development of much more sophisticated spacecraft than the ones now envisioned, operation in electromagnetic spectrum regions significantly higher in frequency than 10 GHz, innovative techniques for transmission and dynamic circuit allocation, and cost-conscious terminal design. Federal research and development in these fields should complement that of industry.

The Board recommends:

*that NASA, in close consultation with those federal, state, local and other agencies and groups representing telecommunications users, and in active cooperation with the industries expected to provide satellite telecommunications equipment and services, annually update and publicize a broad, balanced, and continuing technological development program plan responsive to user needs and effectively complementing the research and development activities of the private sector.*

Rapid technological change has marked the past decade's advances in satellite communications. The international common carriers needed improved reliability and increased capacity on their long-haul trunk circuits, and they had an adequate legal, financial and professional base to incorporate into their systems the orbiting satellite microwave repeaters and surface terminals developed to meet those needs. Advances in the technological capabilities of the international common carriers and their supporting industry can be expected to continue. It appears to the SAB that much of the next decade's activities in the satellite communications area will be aimed at the provision of new domestic services and that a great deal of research and development will be required -- not only of a technological nature but of a market- and service-related nature as well. COMSAT's experience has demonstrated that satellite telecommunications technology can provide circuits of great reliability, range, capacity and flexibility. If the market for public service communications is large enough, circuits could be provided at relatively low cost. To establish whether there is a large market for public service communications, however, will require that telecommunications scientists and engineers work closely with potential telecommunications users such as teachers, public officials, doctors and city planners, over long enough periods of time and with enough thoughtful imagination so that all can ascertain how, to what extent, and under what circumstances, telecommunications could be used to assist in the provision of public and private services in a demonstrably sound, economic and acceptable fashion.

The Board recommends:

*that greater support be given by all of the federal departments and agencies to those research, development and other activities required to explore new ways of using satellite telecommunications to improve, to allow increased access to, and to reduce the cost of providing public services. The Office of Telecommunications Policy should lead in defining and establishing such support and in encouraging innovative private initiatives (as it has in the recent past for a public service satellite consortium), as well.*

Because such research and development activities will involve detailed study of complex social, economic, organizational and institutional arrangements, the Board suggests that they be planned with great care and involve all of the professional disciplines and governmental, commercial and industrial skills needed for their satisfactory conduct.

To avoid such difficulties as attended the move of the ATS-6 satellite to serve India, satellite telecommunications circuits should be made available for the relatively long periods of time inherently required for public-use experiments.

#### A POSSIBILITY FOR THE FUTURE: MATERIALS PROCESSING IN SPACE

Some of the most effective processes for purifying biological materials and for manufacturing or refining inorganic materials are inhibited to some degree by convective mixing which occurs in the presence of gravity when heat is introduced, by intention or otherwise, into the material being processed. Electrophoresis, for example, is widely used for separating, characterizing and analyzing certain biological materials that are difficult to separate. In the electrophoretic process, molecules, groups of molecules, or cells, suspended in an appropriate solution and immersed in an electrical field, move in a direction that depends on the sign of the electrical charge on or near the surface of the molecule or particle and at a speed proportional to the magnitude of the electrical charge. If the electrical charge of the molecule or particle of the substance to be isolated is different from that of other substances in the solution, differences in speed or direction of migration of the molecules or particles may permit fractionating the various species in a mixture. However, ohmic losses occur in the solution, introducing heat into the process. In the presence of gravity, this heating results in convective currents which tend to remix the components. Separation by electrophoresis may not be difficult if the differences in the electrical charges of the species are large, but in some biological materials that would be important in medicine if they could be made sufficiently pure, the differences in the electrical charges of the particles involved are very small, and convective mixing seriously inhibits or prevents fractionation. Even in cases where separation sufficient to permit observation or classification can be achieved, convective mixing may prevent separation if the strength of the electrical field or the volume of solution is increased in attempts to obtain sufficient quantities of the material for further analysis, for culturing, or for other practical uses.



Some of the characteristics of inorganic materials (for example, crystalline perfection, homogeneity of precipitation in multiphase systems, and purity) are adversely affected by gravity when they are processed on earth. Specialized "drop towers" on earth, aircraft following ballistic trajectories, or sounding rockets may be used to provide a gravity-free environment for periods ranging from a few seconds to several minutes, but many processes for the manufacture or refinement of materials require periods of hours, days or weeks to accomplish. The time during which near-zero gravity can be achieved at the earth's surface is not sufficient for experiments with these processes.

Just as importantly, experiments in space may reveal phenomena arising from forces (for example, surface tension) that may be overshadowed by gravitational effects on earth.

In the view of representatives from the materials processing community involved in the study, two experimental areas -- the processing of biological materials and the preparation of inorganic materials such as semiconductors -- warrant further exploration. Both involve materials of significant commercial potential. In each case, preliminary results, even if basically scientific in nature, may provide guidance on how to utilize and/or process materials more effectively on earth.

#### Processing of Biological Materials

Improvements in resolution and specificity of the electrophoretic process in the absence of gravity have been predicted analytically, and to some extent confirmed in experiments in space.\* If processing in space could permit better separation of substances, purer forms of current products might be prepared. New products might also result. The benefits from space processing could be large if certain high cost and low volume biologicals could be prepared in purer form than has been possible on earth. For example, if improved serum used in the transplantation of kidneys and other organs and suitable hormones (such as erythropoietin) or other biological products could be manufactured, relief might be provided to some of the more than 15,000 persons in the United States who suffer from renal insufficiency. Some kidney treatments and transplants are now federally supported. It might be possible, therefore, to provide a direct measure of the costs and perhaps a more exact measure of the benefits of rehabilitation of such persons and thus to develop a clearer rationale for government research and development to reduce these expenditures.

Too, the estimation of benefits might be related to the effects on the pharmaceutical industry of successfully developing processes for making higher purity products. The industry has annual sales of about \$8 billion in the United States, of which about five percent is in biologicals. It is possible that the production and/or quality of a significant fraction of these biological products might be benefited by research in space on purification processes.

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\*M. Bier, J.Q.N. Hinckley et al. "Role of Gravity in Preparative Electrophoresis," *Proceedings of the Third Space Processing Symposium: Skylab Results*. George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Marshall Space Flight Center, Alabama, June 1974, pp. 729-754.

According to representatives of the materials processing community involved in the study, certain biological separations of potential importance in medicine are difficult to accomplish in the presence of gravity. These include:

- the final stages of purification of the hormone erythropoietin (derived from kidney cells) which stimulates production of red blood cells in bone marrow (tens of thousands of patients with kidney disease are severely anemic for lack of the hormone);

- the final stages of purification of the enzyme urokinase (derived from kidney cells) now in large demand to eliminate emboli from the circulatory systems of patients;

- achieving adequate separation of subpopulations of white blood cells (lymphocytes) used in production of antibodies and other products that characterize and may modify the immuno-responses of patients to transplants, nucleation, and growth of tumors and other therapies or pathologies;

- achieving adequate purity in the separation of certain blood proteins that are associated with clotting and other behavioral features of blood, with anticarcinogenicity, and with other functions such as the metabolism of neurochemicals;

- achieving adequate separation among red blood cells (erythrocytes) having different electric charge, dipole layer (zeta potential), density and other characteristics; and

- achieving adequate separation among nerve cells which differ in electrolytic, internal electrical, neurochemical and neurological behavior and functions.

(Similar model materials were suggested in a recent study by a panel of the American Institute of Biological Sciences.\*)

The Board recognizes that it is not expert in biological materials or in their preparation. Knowing that electrophoresis has been used very successfully for separating proteins (and, with more limited success, for separating cells), some experts have questioned whether there is adequate scientific evidence that electrophoresis in the absence of gravity can accomplish separations not now possible on earth. In view of this, the Board has consulted a number of experts in biological materials and has satisfied itself that the problem of separating or purifying some materials (including those referred to herein) is a real one. In addition, the Board has also consulted experts in electrophoresis and has satisfied itself that gravitational effects remain a

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\*Report of the American Institute of Biological Sciences Panel on Electrophoresis in Space to the National Aeronautics and Space Administration (NASW-1901). American Institute of Biological Sciences, June 1974.

limiting factor in certain applications of electrophoresis. The Board has concluded that electrophoresis in space may permit separations not yet achieved on earth or separations in quantities not yet possible to prepare on earth. In the Board's opinion, the importance of achieving better separation or of producing useful quantities of a number of biological materials makes it advisable to explore the possibilities by a small but well-planned program of experiments.

The SAB recommends:

*that NASA, in cooperation with the biological materials industry, undertake a small but vigorous and systematic program of experiments with processes for separating, characterizing, and analyzing biological materials in the prolonged low gravity of space so as to determine whether significant improvements in the processing of such materials can be accomplished in space or, with knowledge gained from experiments in space, on the earth's surface.*

#### Processing of Inorganic Materials

Some processes for refining inorganic materials extend over periods of several weeks. This is particularly true of the growth of some crystals in solution. In a gravity field, nonuniformity in heating causes convective currents in the fluid phase of the material and, in some cases, may significantly affect the end properties. Stirring of the material is frequently a requirement to reduce sedimentation when gravity is present, and this affects the process, sometimes adversely. In the transition from a fluid state to a solid, materials pass through a plastic phase in which gravity induces stresses. The stresses may in turn adversely affect the structural and electrical properties of the materials. In some processes, very high temperatures are employed. In this case, the container in which the process is taking place may enter into the process in an undesirable manner. Processing in space may, in some instances, mitigate the adverse effects of gravity (including convection and sedimentation) and provide isolation from the container. For example, ideal diffusion-controlled steady state segregation (never accomplished on earth) was achieved by a group of scientists from the Massachusetts Institute of Technology during the growth of tellurium-doped indium antimonide crystals in experiments carried on Skylab III and IV.\*

Representatives of the materials processing community who participated in the study suggested that experiments in the processing of inorganic materials might have two types of benefits: (1) improved knowledge about more perfect materials which it may be possible to derive in space and thereby shed light on desirable processes on earth and (2) the possibility of producing very small quantities of highly critical materials that cannot now be produced on earth. The Board believes that these possibilities merit further examination.

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\*A.F. Witt, H.C. Gatos *et al.* "Crystal Growth and Steady State Segregation Under Zero Gravity: InSb," *Journal of the Electrochemical Society*, Vol. 122, No. 2, 1975, pp. 276-283.

The SAB recommends:

*that NASA, in collaboration with the materials processing industries, examine preparation processes for inorganic materials to determine whether any could utilize the space environment to advantage.*

## ORGANIZING TO USE THE NEW CAPABILITY

Weather satellites and communications satellites have already entered into the service of mankind, and satellites for observing the earth's resources are on the verge of doing so. An institution -- the National Aeronautics and Space Administration -- exists for continuing non-defense space-related research and development. If this research and development continues to have the support of the public, the Congress and the President, advancements in technology and thus potential new benefits may be expected. Whether the benefits from practical uses of space systems will even approach full realization depends on our ability as a Nation to organize ourselves to capitalize on these new capabilities. To do so will require the solution of a host of non-technical problems. For example:

there is not as yet any institutional arrangement to provide for that phase in the development of a space system when the technological capabilities of the system have been demonstrated but the user community is not yet aggregated or has not yet had sufficient opportunity to try the system and to decide if it should replace or supplement older methods.

only a very small fraction of potential users are aware of or know how to use the information or services that space systems could provide.

potential users are scattered throughout many fields of activity and in many states, cities, industries and businesses, and thus do not constitute an aggregated "market" to which commerce and industry can easily respond.

available institutional arrangements are inadequate for identifying the needs of potential users so as to provide direct and consistent guidance to technologists and the developers of space systems.

except for satellite communications, there has been little non-federal contribution to funding of development or operation of major space-related systems.



there are, as of now, no provisions for continuing satellite development experiments after *technical* feasibility has been demonstrated. Thus, potential users do not have the opportunity to experiment with the new capability in their day-to-day activities on the ground and to decide what part, if any, this new capability should have in their work.

potential new users have no assurance that if they begin to rely on space-derived information or services, they will continue to be available.

for many of the useful applications of space systems considered in this report, there are not adequate institutional arrangements, private or public, to initiate operational systems. This is particularly evident in areas where different user communities could benefit from a common system.

#### PROVIDING FOR THE TRANSITIONAL STAGE IN THE EVOLUTION OF SPACE SYSTEMS

There is an important transitional stage between research and development and the implementation of an operational applications system. In the transitional stage, the technological capabilities of the system have been demonstrated, but the user community is not yet aggregated or has not yet had sufficient opportunity to try the system and to decide if it should replace or supplement older methods. If the transitional stage is not provided for, systems that could provide important benefits may not come into use.

There is a wide variation in the capability of users to understand the significance of space technology, space-derived data and space-related services and to begin to assess them in terms of their individual operations. Some organizations consider operational (in their terms) their use of experimental and developmental space systems. At the other extreme are large numbers of potential users who have little or no knowledge of space-derived information or services that may be available and who have never had the opportunity to consider whether these services might be of use to them.

Perhaps a greater problem is that of providing to existing organizations -- ones relying on well-developed and long-standing techniques -- the opportunity to objectively evaluate and consider the possible benefits of employing space-based information or services, either to augment or to supplant present methods.

It is clearly impossible at the present time to delineate precisely the dividing line between the proper functions of the federal government and the private sector. The Board believes that federally supported experiments with institutional mechanisms, conducted in cooperation with users in state, regional and local governments, as well as the private sector, should be an integral part of a national program for utilization of space technology and should shed some light on the proper division between functions of the government and functions of the private sector. Such experimental activities should include pilot projects using field testing techniques that:

are not regarded necessarily as precedent setting;

do not imply advocacy of a particular institutional approach;

do not imply continuing federal support; and

provide for independent evaluation.

The expected outcome of such pilot projects would not be standardized institutional models, but rather better understanding of and experience with the various institutional arrangements in different geographical, political, socioeconomic, and cultural contexts.\* Experiments would focus on stimulating the acquisition and use of the products of space systems through specific attention to:

mechanisms to define and assess user requirements. Emphasis should be placed on a diversity of mechanisms and on encouraging the utilization of technical talent from universities, not-for-profit research organizations, and the private sector to assist and to increase user capability.

capability-building programs, to educate the user groups on the nature and potential uses of data and services and on the kinds of software systems needed to utilize them; to provide skill training; to encourage the development of management capability in the use of space-related information; to provide advice to users in adapting multiple-use systems to specific local applications.

methods for aggregating and standardizing requirements by jurisdictional levels, geographic region, and functional areas of use such as earth resources or environmental quality.

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\*For example, a Federal Regional Commission might be asked to work with NASA to establish a set of user requirements for information on a problem of high priority (e.g., an inventory of land use or water resources) for that region. The experiment could be designed to test a set of institutional variables, such as means for involving various jurisdictions (state, county, municipality, etc.) within the region and to assess the effectiveness of various sources of technical capabilities to evaluate information derived from remote sensors and to find ways to implement decisions based on the information. An experiment could be designed to evaluate the involvement of federal laboratories, private industry, universities, or staff professionals of the Commission or its component jurisdictions. The project could be set up with ground rules that clearly establish it as an experimental program, whose basic objective would be to yield information on the best means of working with a user group.

Experiments should be based upon awareness and assessment of previous and current institutional arrangements for technology application; efforts of NASA and other agencies in fostering non-federal involvement; and current experimental efforts at technology transfer, such as those being conducted by the National Science Foundation, the National Bureau of Standards and other federal agencies.\* Provisions should be made for at least some of the institutional arrangements experiments to be designed and proposed by the potential users themselves.

Responsibility for this program should eventually be assigned to an institutional mechanism, discussed later in this report. However, such a program of experimentation should be initiated without delay. Pending the establishment of a new institutional arrangement, the responsibility for initiating the program could be assigned to NASA, with the cooperation and involvement of the relevant federal user agencies.

The Board recommends:

*that experiments with institutional arrangements designed to stimulate users to apply space-derived information and services in their own fields be undertaken as soon as possible by NASA.*

Some authorities consider that the Space Act authorizes NASA to work in the transitional phase. Others do not.\*\* Under the circumstances, NASA has refrained from carrying demonstrations beyond indication of technical feasibility. As a result, potential users have not had adequate opportunity to evaluate new services. The Board suggests that a review of the NASA charter as it was set forth in the National Aeronautics and Space Act of 1958 be undertaken in the context of emerging large-scale applications of space technology.

The Board recommends:

*that Congress clarify the extent to which NASA should be involved in the transitional phase of space system applications.*

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\*Federal Obligations for Management, Processing and Transfer of Scientific and Technical Information Data and Technology, FY 1969-73. Prepared for the Office of Science and Technology, Executive Office of the President. Government Printing Office, Washington, D.C., 1972.

\*\*The functions of the National Aeronautics and Space Administration, as set forth in Section 203 of the National Aeronautics and Space Act of 1958 (Public Law 85-568), are to: (1) plan, direct, and conduct aeronautical and space activities; (2) arrange for participation by the scientific community in planning scientific measurements and observations to be made through use of aeronautical and space vehicles, and conduct or arrange for the conduct of such measurements and observations; and (3) provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof.

## THE NEED FOR A NEW INSTITUTIONAL MECHANISM

There exists at present no institutional mechanism that permits the large body of potential users -- which the Board sees as existing in federal agencies and in state and local governments, in industry and the business community, and in educational institutions -- to express their needs and to have a voice in matters leading to the definition of new systems. To date it is the providers of space systems who devise what they believe are useful requirements and proceed to build experimental systems. They then find themselves in the position of trying to "sell" this technology to prospective users. While this process works well (and needs to be continued) for stimulating technology, it needs to be reversed with regard to involvement of the users. The Board perceives a need for some institutional mechanism designed to assure user participation in defining new applications.

The institutional problems are ones of organization, communication and leadership -- problems which can only be ameliorated by establishing some means in addition to those which the Nation has developed to date for dealing with space technology. The Board believes such a mechanism (or mechanisms) is required to serve the following functions:

*Provide general policy direction:* There is need for a focal point where questions of the initiation of major space applications programs of potential national interest, their utility, growth, effectiveness and direction can be debated and decided -- subject, of course, to review by the Congress and the President of the United States.

*Set priorities:* As the information and services provided by space-based systems enter into wider use, there will be competing demands for those services requiring priority decisions regarding funds, personnel, facilities, and launch services. Methods in addition to those employed in the past for developing technology alone are needed to decide under what conditions and in what order organizations with competing needs are entitled to use such national resources.

*Establish pricing policy:* Procedures, made generally known to all potential users, are needed for pricing federally funded products and services and the use of national facilities.

*Provide for communication between users and providers:* To supplement the normal and generally useful informal contacts between providers and users of space-derived information and services, there is need for a structure within which formal exchange of ideas, proposals, criticisms and evaluation of space-related applications can take place. It is particularly important to assure regular and effective input to planning of federal space applications programs from non-federal entities -- that is, from states, metropolitan areas, counties, cities and the private sector -- which might be important users.

*Encourage non-federal investment:* Private capital will be attracted to invest in space systems designed to provide marketable goods and services only if the risks and the returns are perceived as reasonable. The risks and returns are particularly difficult to assess at the transitional phase in the development of a space system. Leadership is needed to encourage federal agencies (both operating agencies and regulatory agencies) to find ways to reduce the risks to the private sector and assure a reasonable return to private capital invested in space systems. For example, under current procedures, if a company pays NASA for the launch of a satellite and the launch vehicle fails, the company loses the costs of the launch vehicle and the launch operation (as well as the cost of the satellite). NASA has examined the possibility of imposing an additional charge deemed sufficient to recover for the federal government, on an actuarial basis, the cost of launch failures from the total group of private sector users. Under existing laws and regulations, however, monies recovered by the additional charge would revert to the Treasury rather than becoming available to NASA to pay for replacement of the failed launch vehicle. Under these circumstances, NASA has not found it possible to guarantee launches, and the risk to the individual buyer of a launch remains.

#### SOME OPTIONS

The Board has examined the advantages and disadvantages of four options for institutional mechanisms to perform the functions just discussed.

##### Option I - An Existing Operating Agency

This option consists of placing in one of the existing federal agencies having a major interest in space technology, the prime responsibility for performance of the required functions, and the authority -- subject to appeal to or review by the President -- to settle disagreements or make allocative decisions. This would not rearrange present assignments, operating responsibilities or location of substantive expertise. It would simply establish a lead agency with final authority and responsibility, much as the State Department operates in the field of foreign affairs. This option would require formal arrangements by which other agencies and non-federal users could be consulted prior to decisions and by which the lead agency could be kept informed about actions on its decisions and the results thereof. This option has a number of advantages including clear lines of authority, low cost, and rapid start-up. However, in the Board's opinion, it would be unworkable in practice. Programs would be subject to bias in favor of the mission of the chosen agency. The lead agency would be in the position of making judgments about the work of other agencies. Refusal of agencies to accept subordinate status would lead to pressure for splintering of functions and multiple requests for exceptions from the authority of the lead agency.



## Option II - A New Agency Established for the Purpose

This option assumes the creation of a new agency whose sole purpose is to perform the functions discussed at the beginning of this section. Operational responsibilities of existing agencies would remain undisturbed. Analogous examples might be the original form of the Office of Economic Opportunity (less its operating functions) or the role of the United Nations Development Program vis-a-vis the U.N. Specialized Agencies. In both of these cases, the principal leverage of the coordinating agency has been that the bulk of the funds involved flowed through it, as would be the case for this option. To be effective, the agency might have to be placed in the Executive Office of the President.

The lack of any historical bias or prior operation within the government is one advantage of this approach. In addition, existing agencies might find a new agency easier to accept than a lead agency selected from among them. Disadvantages include potentially high cost and slow start-up. Further, as in the case of Option I, the specialized constituencies of existing agencies could be expected to make it difficult for the new agency to function effectively. Most importantly, however, this arrangement would result in an unacceptable level of duplication, and would not necessarily reduce the problems of potential users in dealing with the federal establishment.

## Option III. A Space Applications Corporation Chartered by Congress

Option III consists of a congressionally chartered private corporation which would have as its business the development and operation of space systems for practical use, and would develop the market for and sell for profit the resulting space-derived information and services. The corporation would be supervised by a board of directors, the composition of which would be determined by the Congress to assure adequate consideration of the interests of the public and of the private sector. The corporation would be financed initially by congressionally appropriated funds, and later -- as it developed a market for its products and services -- by the sale of stock.

The Communications Satellite Corporation (COMSAT) is an example of such a corporation. COMSAT was established by the Congress in 1962 to plan, develop and implement a commercial communications satellite system, and is regulated by the federal government.

The corporation considered in this option would seek out user needs and translate them into system requirements, aggregating them to arrive at efficient common-use systems. The corporation would define the systems characteristics, procure systems from the private sector, pay for launch of the space element of the system, contract for operation of the system after proper functioning of the space element had been verified, process the data obtained and provide customers with the needed information or services. The corporation would work closely with the user community, with the suppliers of technology (government agencies, universities, not-for-profit research centers), and with the suppliers of systems (the aerospace and electronics industries) in the role of a coordinator, integrator and financier.

This option assumes that it is in the public interest to assign responsibility for the operation of space systems to a single federally created corporation

rather than leaving it to commercial competition because: (1) the potential economic significance of earth observations requires regulation to protect the right of access to the data on an equal basis; (2) earth observations cross private property lines and local, state and national political boundaries, and inherently involve observations of the property of others (and thus the data obtained should be considered as property common to all citizens); and (3) the benefits of the systems can be perceived as accruing from a major investment of the taxpayers' money in research and development performed by the federal government.

Advantages of the private corporation include the motivation to show a profit, relieving the federal government of involvement in operational systems, and the incentive to interact with users of information and services and with the suppliers of technology to assure that the product matches the need.

Disadvantages include the fact that central planning, review and control of government agency activities related to space systems would not be achieved. The goals of the private corporation might not be compatible with national goals. Most importantly, however, it is questionable whether the Executive Branch and the Congress could agree on formation of such a corporation until the transition phase of systems had been carried sufficiently far to enable the private sector to assess risks and returns, and thus attract private capital. In the case of COMSAT, there was an aggregated market already in existence: common-carrier communications companies were enthusiastic about the possibilities of satellite communications. Few or none of the elements of this favorable environment exist at this time for space-derived services other than the common-carrier communications of the type provided by COMSAT.

An additional disadvantage is the length of time that would be required to resolve the complex industry-government interface, with its legal, social and financial aspects that must be negotiated, debated and decided at the highest national levels. In the case of COMSAT, several years were required to work out an acceptable industry-government interface. Additional legal, organizational, national security or other difficulties could be experienced in the international arena.

#### Option IV - A Congressionally Mandated National Council

This option envisages the formation by Congress of a National Space Applications Council, established by statute and charged with responsibility for the following functions for all practical applications of space systems: general policy direction; priority setting; assurance of continuity and standardization; price setting; establishing formal contact between users and suppliers; coordination of program implementation and evaluation of program development; and encouragement of non-federal involvement and investment. As in all federal programs, this authority would be subject to review by the Congress and review and approval by the President.

The Council would include as participating members representatives, at the Under Secretary level, of all federal agencies with legitimate and substantial interests in the use of space systems for practical purposes. This would include appropriate Departments of the Executive Branch, NASA, the National Science Foundation, and certain other independent agencies (the precise list

would be arrived at in preparing the authorizing legislation). State and local government agencies would participate and the law would direct the Council to evolve effective and equitable means of assuring their representation. These non-federal representatives would acquire voting status as soon as possible and certainly within a very few years.

The Council would be charged with (1) building a nationwide process whereby user views are solicited, aggregated, and taken into account, (2) determining the U.S. role in such a process worldwide at such a time as this becomes appropriate, and (3) developing a procedure by which, where possible, non-federal interests gradually assume (under federal regulation) control and funding of space systems and their applications as they become operational. Delegating these responsibilities to the Council does not imply that weakening connections between operating agencies and the user community is necessary or desirable.

The Council would be required to prepare for the Congress an annual report summarizing major issues and decisions, outlining future plans and assessing future implications. A strong commitment to open debate and full disclosure has been one of the strengths of the U.S. space program, and this commitment should be carried over to operational space systems so that full public advantage can be had from investments in the space program.

A congressional mandate would be needed to provide clear accountability for the performance of assigned functions. Such authority would also be needed to provide for the Congress and for the Executive Branch a means of measuring the value of space applications on a broader basis than has been possible to date.

Option IV offers a number of advantages. It could be brought into being without major delay or organizational perturbations. It provides equal status for representatives of the participating agencies. No changes would be required in existing structures or agencies, congressional constituencies, appropriations or operating responsibilities. The Council would bring officials responsible for research and development together with officials responsible for operational systems in a forum conducive to planning and implementation of transitional phase demonstrations, designed to identify the market and to permit assessment of costs, benefits and risks associated with an operational system. Under the Council, applications of space techniques would be motivated by user needs and not solely by individual agency interests, the exigencies of the federal budget at any given time, or industry profits. A good mechanism would thus be provided for setting priorities. State, local and private participation could be assured. A unified program and a coordinated budget could be developed.

It is recognized that there is much in history to support skepticism about the effectiveness of an interagency group, particularly one that must include representation from most of the large agencies in the government. Statutory authority could mitigate this weakness by providing a clear assignment of responsibilities. Interagency representation, together with that from state and local agencies, would help to keep all participants aware of priorities and problems in different fields and reduce tendencies to parochialism. There are examples of reasonably effective interagency groups, and the Board believes that there is reason for confidence that, in the evolution of the LANDSAT program, a pattern of cooperation among space-interested agencies has been established that can carry over into a broader structure.

## A RECOMMENDED INSTITUTIONAL ARRANGEMENT

If the Nation is to achieve the full benefits that the services and information space systems potentially can provide to the public, to industry and to local and state government, regional authorities and federal agencies, it must be organized to do so. Because the activities of a number of federal agencies would be importantly affected, it is the Board's judgment that it would be unwise to place responsibility for the broad functions that must be performed in an existing federal agency (option I) or in a new federal agency. (option II).

The Board believes that a congressionally chartered Space Applications Corporation (or Corporations) will come into being when users have had the opportunity to try space-derived services in their fields for an appreciable time through transitional phase demonstrations, when more work has been done to aggregate the market for such services and when there is sufficient evidence that the market will be profitable. In the Board's opinion, it will take at least three to five years for these conditions to be fulfilled.

It is the Board's judgment that, at the present time, the National Space Applications Council, described as option IV, offers the best promise of organizing activities, both in the public and the private sectors, to begin to realize real benefits from the substantial national investment in the space program.

Accordingly, the Board recommends:

*that there be established by statute a National Space Applications Council, charged with responsibility for the following functions for all practical applications of space systems: general policy direction; priority setting; assurance of continuity and standardization; price setting; establishing formal contact between users and suppliers; coordination of program implementation and evaluation of program development; and encouragement of non-federal involvement and investment.*

Upon its establishment, the Council should take over responsibility for the experiments with institutional arrangements designed to stimulate users which were recommended earlier in this report.

## SOME OBSERVATIONS ON BENEFITS AND COSTS

As noted earlier, it is not the intention in this study to make specific cost-benefit analyses, but rather to inquire into whether such analyses are feasible, in what fields they should be conducted, and in general to consider what should be done to arrive at an acceptable basis for making decisions concerning investments in research and development related to practical uses of space systems.

It appears to the SAB that to date cost-benefit studies of space systems have been essentially analytical studies, relying on the standard concepts and tools of economic analysis and built around whatever relevant data were available. As in any study, the ground rules established in advance and the assumptions made have been crucial to the outcome. For example, a study of costs and benefits for a few cases of uses of earth observations was recently conducted for the Department of the Interior.\* This study was concerned with the question of whether it would be productive to proceed with an operational system *using the existing LANDSAT sensors*. Thus, the ground rules for this study precluded taking into consideration improvements in remote sensing technology that might come about over the next several years. (Similarly, potential improvements in the sensors for a competing high altitude aircraft system were not considered.) Only benefits from fully proven uses of LANDSAT data were considered. Benefits that might accrue from improved forecasting of agricultural production were excluded as neither proven nor disproven. As a result, the estimates in this most recent cost-benefit study are considered by the SAB to be overly conservative for both space and aircraft systems.

The Board feels that it is time to take steps to assure that better data and broader professional experience relevant to analysis of costs and benefits will be available. It has been recommended earlier in this report that the plan for the Large Area Crop Inventory Experiment provide for observation of those parameters needed for cost-benefit estimates relative to an operational system. In fact, this should be done in most research and development programs that anticipate eventual large-scale operations.

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\**Earth Resources Survey Benefit-Cost Study*. Prepared by the Earth Satellite Corporation and the Booz-Allen Applied Research Corporation for the U.S. Geological Survey. U.S. Department of the Interior, Geological Survey, November 1974.



Accordingly, the Board recommends:

*that, wherever possible, the plans for experiments in the practical use of space systems make specific provision for observation of all parameters significant to eventual cost-benefit analysis.*

The Board considers that, given time and the appropriate input data, it is possible to make cost-benefit studies sufficiently valid to be used in the decision process for the research and development, transitional, and operational phases of space applications. The Board points out, however, that while such studies should be made in-depth prior to decisions related to operational systems, the same depth is not possible for, nor should it be required for, the research and development and the transitional phases. The Board also feels that cost-benefit analyses related to operational applications should take into account, broad end goals, such as adequate supplies of food, energy, and minerals, rather than the much narrower objectives which typify studies made to date.

The Board recommends:

*that cost-benefit studies in anticipation of operational systems be conducted in the areas of food supply and distribution; energy sources and distribution; mineral discovery; and environmental quality.*

The Board is confident in its belief that the use of space systems to assist in the solution of some of mankind's everyday problems is, and should continue to be, beneficial. It should be possible, given time, to quantify future benefits. Based on rough estimates, the Board believes that when such calculations are made, the benefits in many cases will be shown to exceed the costs by a substantial margin. This report has outlined some of the needs that space-derived information or services might be able to satisfy. The following examples give some measure of the potential dollar benefits.

According to the land use planners involved in the study, state and local governments are currently spending about \$480 million annually to acquire and to keep track of land use data. These planners estimated that an operational space-based remote sensing capability augmenting existing aircraft and ground-based systems might save a significant fraction of these data costs.

Agriculturalists involved in the study estimated that a World-wide Agriculture Survey using an integrated system drawing on data from LANDSAT, EOS, SEOS, SMS,\* NIMBUS, AND SEASAT, plus currently existing aircraft and ground-based systems, could

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\*EOS is a projected operational Earth Observatory Satellite; SEOS is a synchronous orbiting version of EOS; and SMS is the Synchronous Meteorological Satellite.

yield to the United States cumulative benefits, arising from increased production, improved distribution, better import-export decisions, and reduced costs, exceeding \$8 billion in current dollars. It is believed that the cost of developing and operating the integrated system would be considerably less than that amount.

The Water Resources Planning Act of 1965 stipulates that a national inventory be made biannually. To date only one inventory has been made and it was less than satisfactory because basic data were lacking on both the supply and the use of water and because, at that time, there was an almost complete lack of data on the quality of the Nation's water. Currently another national inventory is under way at an appropriated cost of \$605 million. Representatives of the water resource management community involved in the study estimated that the actual cost of the inventory will be about twice the amount appropriated if conventional means of data collection are used. They estimated that a significant part of these data costs could be saved if space-based remote sensing were added to current capabilities.

Cargo and shipping losses caused by weather are now \$500 million annually. Representatives of the maritime community involved in the study have concluded that improved wave and weather forecasts, which space systems might make possible, could permit important reductions in these losses. They further concluded that improved routing which space-based navigation could make possible, would permit important additional savings in the \$450 million fuel cost currently experienced in transatlantic service by the U.S. flag fleet, of 570 ships.

Future costs are almost as difficult to estimate as future benefits. If the current Space Shuttle payload model\* is realized in the 1980-91 era, by 1991 the cumulative costs of the space applications portion of the payload model could amount to about \$11 billion in 1972 dollars for payloads, launch operations and data acquisition. The payload model projects 60 Shuttle flights per year for all uses, of which about 20 flights are for applications missions. A significant number of the latter are projected to satisfy private users who might be expected to pay for the service, having independently judged the benefits to exceed the costs. Although these projections are the best that can be obtained, the Board considers these cost estimates to be little more than instructive because of the difficulty of predicting so far into the future,

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\*Space Shuttle Payloads: Hearings on Space Missions, Payloads, and Traffic for the Shuttle Era. U.S. Senate Committee on Aeronautical and Space Sciences, October 30, 1973.

especially given the present limited experience with large-scale practical applications of space systems. The difficulty of making sound projections emphasizes the importance of careful planning for in-depth studies of operational systems recommended earlier.

## ACCESS TO SPACE -- A COMMON NEED

Users and potential users of space-derived information and services will need continued access to space by means of a transportation system that is both easy to use and reasonably priced in terms of the benefits to be achieved. The present space transportation system -- which does not fully meet ease of use and cost requirements -- consists of launch vehicles (such as Delta, Titan and Centaur) that are expended in a single use. NASA is developing for use in the 1980's a space transportation system designed to provide easy access to space and to reduce costs by reuse of major system elements. The system will include a reusable manned vehicle (the Space Shuttle) with a cargo bay and a propulsion stage, called the Tug, to be carried into low earth orbit by the Shuttle. The Tug, planned for later development, will move space applications and space science payloads from the Shuttle's low earth orbit (about 185 km) to higher altitudes, including geostationary orbit (about 41,000 km) and beyond. An additional element, intended to be carried into earth orbit by the Shuttle, is a habitable space laboratory, appropriately named Spacelab, which is being developed by the European Space Research Organization (ESRO). Those space applications and space science tasks that could benefit from the presence of humans could be carried out in Spacelab.

It is planned that in the early 1980's, space transportation services will begin to be provided by the Shuttle system instead of by expendable launch vehicles. The study panels concluded that the planned performance of the Space Shuttle system, assuming polar and geosynchronous orbit capability, will adequately accommodate spacecraft to meet foreseen user needs.

The Board emphasizes that to satisfy the information or service needs expressed by the study's user panels will require -- in almost every user category -- spacecraft in either polar or geosynchronous orbits. To the best of the Board's knowledge, present plans for these Shuttle system capabilities are not firm. If there is not, then, to be a lag in meeting the launch needs for applications satellites when conventional launch vehicles are phased out and the Shuttle becomes the operational launch vehicle, firm planning should provide for an early north-south launch capability so that the Shuttle can place payloads in polar orbit. Similarly, means for transferring payloads from Shuttle orbit to synchronous orbit should be available at the time the Shuttle becomes the operational launcher.

The Board recommends:

*that to meet the needs to place applications payloads in polar and geosynchronous orbits, both north-south launch capability, and the Tug, be firmly planned for availability with the earliest operational Space Shuttle system.*

To avoid the possibility of lag in launching applications satellites, will require maintaining conventional launch vehicle capability during the transition to Shuttle operation and until the Shuttle system provides the capabilities of polar and geosynchronous orbits. The alternative would be to forebear from or delay the beneficial uses of satellites as perceived by the user panels.

The Board recommends:

*that conventional launch vehicle capability be maintained to permit launching applications payloads until the Shuttle system, including capacity for both polar and geosynchronous orbits, becomes operational.*



## IN CONCLUSION

In preparing this report, the Space Applications Board has drawn heavily on the work of a group of potential users of the information and services that earth-orbiting satellites could provide. Convened for a two-week period during the summer of 1974, the users, senior and experienced in their respective fields, came from the world of federal, state and local government, and from business and industry. Their concerns were with very real problems, such as assuring adequate supplies of food, water, and energy, protecting man's physical environment, and providing services for the public good, such as communications, navigation and weather forecasting. Many of the potential users had little or no knowledge of practical uses of satellites, and they came to the study with a healthy skepticism about the usefulness of space systems. *Perhaps the most important result of the study is the fact that as the user panelists began to understand what the current and future possibilities were, they perceived useful services that could be applied to their activities, whether in the public or in the private sector.* The study concluded with a conviction on the part of the users that widespread use of information and services derived from space systems should be encouraged, and that means should be found to implement the systems that they saw as needed.

It seems clear to the Board that space systems can serve the Nation in many new ways. It seems equally clear, however, that present institutional arrangements are not adequate to permit the Nation to realize in a timely manner all of the potential benefits that space systems can provide.

The Board hopes that the recommendations it has made in this report -- dealing with user needs, with technology and with institutional arrangements -- will help to assure that the national investment in space technology brings full returns in the service of man.

## ACKNOWLEDGMENTS

The Board gratefully acknowledges the hard work -- often nearly around-the-clock -- that the panel members performed at Snowmass. The federal agency advisors to the panels worked equally hard toward the study's success and their contribution is gratefully acknowledged. Both of these dedicated groups are listed in Appendix II of this report.

The Board wishes to express its particular appreciation to Willis Hawkins, who served as Deputy Director of the study and who led an editorial group to weigh panel conclusions, inter-relate them and propose overall judgments for this report, and to Harold Finger, who with certain members of the Board served on the editorial group.

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Many others attended the study and provided valuable advice or assistance, including:

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## APPENDIX I

### SUPPORTING PAPERS

National Research Council. *Practical Applications of Space Systems, Supporting Paper 1, Report of the Panel on Weather and Climate*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 2, Report of the Panel on Uses of Communications*. National Academy of Sciences, Washington, D.C. 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 3, Report of the Panel on Land Use Planning*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 4, Report of the Panel on Agriculture, Forest, and Range*, National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 5, Report of the Panel on Inland Water Resources*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 6, Report of the Panel on Extractable Resources*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 7, Report of the Panel on Environmental Quality*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 8, Report of the Panel on Marine and Maritime Uses*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 9, Report of the Panel on Materials Processing in Space*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 10, Report of the Panel on Institutional Arrangements*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 11, Report of the Panel on Costs and Benefits*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 12, Report of the Panel on Space Transportation*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 13, Report of the Panel on Information Services and Information Processing*. National Academy of Sciences, Washington, D.C., 1975.

National Research Council. *Practical Applications of Space Systems, Supporting Paper 14, Report of the Panel on Technology*. National Academy of Sciences, Washington, D.C., 1975.

APPENDIX II

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